Large-Scale Utilization of Saline Groundwater for Development and Irrigation of Pistachios *(P. integerrima)* Interplanted with Cotton *(G. barbadense)*

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Abstract

Cotton has long been considered a salt tolerant crop, but despite many small-scale field trials over 30 years almost no marginally saline water in the San Joaquin Valley of California is used for commercial-scale production. Over this same period water costs have increased four to tenfold, cotton prices have stagnated and more than 100,000 ha have been converted to pistachios. Work in Iran, salt tank studies at the USDA Salinity Lab, Riverside, and a small plot study in the southern San Joaquin Valley indicate pistachios may tolerate a soil extract salinity (EC_e) of up to 9.4 dS/m, but this has not been proven on a commercial scale in California. Such a trial was established in 2004, using 7.9 ha test plots over two 62.7 ha fields to test the use of saline irrigation water for development of a new pistachio orchard interplanted with cotton using shallow subsurface drip tape. Cotton yield and pistachio development were unaffected by salinity for the first two years of this trial at an irrigation water EC of 5.4 dS/m and B concentration of 11 mg/L. Average soil salinity doubled by the end of the first season under saline irrigation compared to fresh water (EC = 0.5 dS/m), but was sufficiently reduced by 250 mm of winter leaching and spring cotton germination irrigation with fresh water to prevent adverse impacts the second year. However, early season stand establishment and growth of cotton in the third year (2006) was reduced for the saline well treatment compared to fresh water irrigation despite application of 450 mm of fresh water for leaching/germination to all plots. Pistachio shoot growth and increase in rootstock girth for this second year after planting was unaffected.

INTRODUCTION

More than a 100,000 ha of the Westside of the San Joaquin Valley (SJV) in California are impacted by saline soils and shallow, saline water tables. Severe restrictions on drain water disposal in recent years, combined with decreased imported irrigation water supplies has accelerated interest in finding salt tolerant crops that are more profitable than cotton. Pistachios have been grown in some of these areas for almost 30 years but always with low salinity (< 1 dS/m) irrigation water.

A recently completed nine year field study on the salt tolerance of pistachios on the Westside of the San Joaquin Valley (Ferguson et al., 2003; Sanden, 2004), and previous pistachio studies in Iran (Fardooel, 2001) have shown the viability of using saline water up to 8 dS/m for irrigating these trees. A rootstock trial in sand tanks at the USDA Salinity Lab in Riverside (Ferguson et al., 2002) showed significant increase in leaf burn with 10 ppm boron in the irrigation water but no reduction in the biomass of one-year old trees. Salinity and B tolerance of cotton has been reported at similar levels in sand tank (Ayars and Westcott, 1985) and long-term field trials (Ayars et al., 1993).

In 1990, State Water Project allocations to Westside irrigation districts went to zero; unleashing California's infant water market with the establishment of "Emergency

Pool" water that drove costs to \$80 per ML or more. Given the salt tolerance of cotton and other rotation crops on the Westside (such as processing tomatoes), some studies investigated utilizing fresh water blended with drainage from tile systems as a means of boosting available water supplies for furrow irrigation (Ayars et al., 1993; Sheenan et al., 1995). This approach generated some interest, since yields were maintained at similar levels to fresh water irrigations, but required a high degree of management with the possibility of long-term residual salinity problems that growers did not want to deal with.

At the same time a number of studies investigated the use of thick-walled drip tubing for permanent subsurface drip irrigation (SDI) as a means of increasing water use efficiency. This system usually increased irrigation uniformity and efficiency, reduced deep percolation, helped to control perched water tables and boosted yield to some degree. Due to the high capital cost, however, the SDI system was less profitable compared to furrow irrigation (Fulton et al., 1991).

Fifteen years later, water costs in some Westside districts exceed \$120 per ML, allocations to growers have been reduced and cotton prices have stagnated. On the other hand, drip-tape systems have improved in quality and can often be installed for \$2,200/ha. The objective of this trial was to assess the production-scale sustainability and long-term profitability of developing young pistachios using saline groundwater interplanted with cotton and irrigated with drip tape.

MATERIALS AND METHODS

Irrigation System and Treatments

In 2004, twelve 7.89 ha test plots were arranged in a randomized complete block design within two 62.7 ha fields (Field 9-1 and 9-3) for a total of 94.7 ha of trial area. Each field had 16 separate automatic pressure regulating subunit valves (Four valves in each field are excluded from this trial.). T-Tape (TSX 708-12-220), 22mm diameter drip tape with emitters every 0.305 m was injected at 0.25 m below field grade in January 2004. Designed for a final tree spacing of 6.7 m between rows, the tape was installed to allow for four 0.97 m rows of cotton between tree rows. Two drip tapes were also injected 0.97 m apart on either side of the future tree row. Rows were 390 m long. This arrangement allowed for a solid planting of pima cotton (*G. barbadense* 'Delta Pine 340') from 11-25 March with two 1.4 m "skips" every six rows. Two manifolds were connected to each valve to allow for separate irrigation scheduling of pistachios and cotton, but for 2004 both manifolds were run as a unit for the solid cotton planting. The average application rate of the six hoses over the 6.7 m spacing was 45 mm/day.

Due to extremely low effective annual rainfall (< 75 mm), partial recharge of depleted soil moisture is done during winter when flood release water is available for reduced cost. Additional fresh water was applied every spring just after planting cotton to "irrigate up" the plants, for a total of 250 to 450 mm (depending on the year) of fresh water applied uniformly across all plots. The respective irrigation treatments were then applied for the rest of the season. Treatments were as follows: AQUEDUCT – low salinity (0.5 dS/m) canal water, BLEND – blended well and canal water (3.0 dS/m) and WELL – pumped groundwater (5.4 dS/m) (See Table 1 for quality data). Salinity of the groundwater was due to a combination of the marine nature of the soil parent material and leaching of saline water separated from nearby oil wells.

In 2005, pistachio rootstocks (*P. integerrima* Stewart × Brandis 'Pioneer Gold 1' (PG1)) were planted March 5-11 at a 5.5 x 6.7 m spacing. Blocks of 20 UCB (*P. atlantica* × *P. integerrima* 'UCB1') rootstocks were planted adjacent to the PG1 trees at all replicated monitoring sites to allow for evaluation of differential vigor/salt impacts from a rootstock interaction. Four rows of DP340 pima cotton were interplanted and irrigated-up between March 25 and April 15. At this spacing the cotton receives 50 mm/day and the pistachios receive 15mm/day from the two adjacent hoses. All pistachio trees were budded with *P. vera* L. 'Kerman' August 12-19.

Soil Moisture Status Monitoring

For the 2004 cotton season, neutron probe access tubes were installed in Blocks 1, 2 and 3 to a depth of 1.8 m in the plant row adjacent to the driptape at 46 m from the head and 91 m from the tail ends of the drip tape. Soil water content was measured weekly using a Campbell Pacific Nuclear 503DR Hydroprobe (Concord, California, USA). In replication Block 1, 6 electrical resistance blocks (Watermark®, Irrometer Co., Riverside, California, USA) were used to estimate treatment matric potential at the 0.3, 0.6 and 1.2m depths adjacent to neutron probe access tubes. An AM400 data logger (M.K. Hansen, Wenatchee, Washington, USA) records these readings every 8 h. Small flow meters were installed at the entrance to each replicated run of drip tape adjacent to neutron probe access tubes. For the 2005 season, a similar network of access tubes and resistance blocks was set up for the newly planted pistachios and reinstalled in the cotton after planting. "Tail" end monitoring of soil water was deemed unnecessary for the 2005 season due to the high uniformity of the system. Instead, neutron probe access tubes were also installed in Block 4 to increase replication.

Soil and Water Salinity Monitoring

Replicated soil samples were taken at germination and post harvest each year from the area adjacent to all access tube locations from the 0-0.15, 0.15-0.45, 0.45-1.2 and 1.2-1.5 m depths and analyzed for EC_e, Ca, Mg, Na, Cl, HCO_3, and B. Treatment water samples were collected in June and the end of August (near irrigation cutoff) and analyzed for EC, Ca, Mg, Na, Cl, HCO_3, and B. In addition, biweekly (June – Aug) treatment water samples were checked with a portable EC meter. Seedbed EC_e for each treatment at the time of cotton emergence was determined by a transect of closely spaced samples taken perpendicular to the drip tape to a depth of 0.5 m. A similar transect was taken for pistachios but with wider spacing. Characterisation of an "average" treatment transect was obtained by compositing separate samples of the same grid spacing from 5 separate transects about 10 m apart along the same bed.

Plant-Based Monitoring

Leaf water potential (LWP) was measured biweekly once cotton plants were about 0.3 m tall. Petiole NO_3, P, K, Na, Cl and B were determined near peak bloom and again just before defoliation in September. Pistachio rootstock leaf tissue was also sampled for the same constituents. Foliage was rated visually for leaf burn. Plant mapping was done in July and just before defoliation. Field seed cotton yield for all plots was determined using a commercial spindle-type picker. Final lint yield/turnout was determined from subsamples and roller ginning. Trunk circumference in pistachios was measured at the start and end of the season.

Mapping Apparent Soil Salinity and Aerial Imagery

The 94.7 ha of trial area was mapped for apparent soil salinity (EC_a) using electromagnetic inductance from a tractor mounted dual dipole Geonics EM38 (Mississauga, Ontario, Canada) and GPS coordinates from the USDA Salinity Lab in Riverside, California from 5-27 May, 2004. This data was compared to field aerial imaging analysis (Ag Recon of Davis, California) shot on 29/7/04. Reflectance was digitally recorded for three different band widths: visible red light (VIS; 0.4 to 0.7 µm), near infrared (NIR; 0.7 to 1.1 µm) and far (thermal IR; 6 to 15 µm) infrared. The relative intensity of thermal IR and the Normalized Difference Vegetation Index (NDVI) was calculated for each plot where 1 pixel equals a 2 meter diameter. As plots were 134 m wide x 390 m long this equals 13,065 pixels per plot – providing a much greater number of pixels for analysis than is often available for replicated studies.

RESULTS AND DISCUSSION

Water Quality and Irrigation Management

The EC of well water over 2004-5 varied from 4.04 to 5.69 dS/m, slowly increasing due to incursion of oilfield leachate water into the well's cone of influence. Table 1 lists the average quality for all irrigation treatments. Mean Na, Cl and B specific ion concentrations for the WELL treatment were 23.0, 33.5 meq/L and 11.1 ppm, respectively, or 3 to 10 times the recommended "no problem" levels for irrigation water listed in FAO 29 (Ayers and Westcott, 1985).

The drip tape system had an average distribution uniformity (DU) of 94.9% over 3 tests over 2 years with only one test sample emitter found to be plugged. The average depth of irrigation from the catch test was 59 mm/day for the 0.97 m cotton row spacing. This is 15% higher than the manufacturer's specified flow rate at the grower's standard operating pressure of 103 kPa (15 psi), but may be an artifact of errors in the evaluation. The average flow for several entire tape lengths (measured by small flow meters serving separate hoses) was 49 mm/day. Most irrigation sets were 24 h duration and measured 48 to 54 mm/day throughout the season.

Using the local state-sponsored agrometeorology station estimate of potential evapotranspiration (ETo) and published crop coefficients (Pruitt et al., 1987) the calculated cotton evapotranspiration (ET) for the 2004 season was 970 mm. Table 2 shows that total applied water averaged 834 mm for the 2004 season and 774 mm for 2005.

Soil Water Content and Salinity

Soil water content for the AQUEDUCT treatment showed consistent decline at the 1.5 m depth from the start of both seasons. The season average "available water %" (using a soil water content of 9.1% for dry and 25.8% equal to field capacity) to 1.8 m in the AQUEDUCT and BLEND treatments was significantly less than the WELL at 68, 70 and 95%, respectively (Table 2). Average soil matric potential followed a similar trend. These data indicate that the increased osmotic potential of the WELL water restricted ET.

The increase in average EC_e to 1.5 m was used to calculate the increase in the mass of soluble salts remaining in the profile at the end of the season (using 640 mg/kg = 1 dS/m EC_e and an average soil extract saturation percentage, SP = 40.7%). This number divided by the mass of salts applied in the respective irrigation water treatments provides an indication of irrigation efficiency. This increase, expressed as a percentage, was 189, 75 and 64% for the AQUEDUCT, BLEND and WELL treatments, respectively. A more accurate estimate of the leaching can be obtained from the chloride mass balance. Again expressed as a percentage of the increase over applied this number was 304, 96 and 74% for the AQUEDUCT, BLEND and WELL treatments, respectively (Table 2); meaning that the leaching fraction (LF) was 0% for the AQUEDUCT treatment, 4% for the BLEND and 26% for the WELL. Leaching fractions approaching 30% will result in average rootzone ECe at or slightly below the EC of the irrigation water (Wu, 2004; Oster and Rhodes, 1990).

2005 had a cold spring, late cotton planting, excessive summer heat and ultimately poor yields. Winter and germination irrigations produced substantial reclamation in cotton beds in the area of the drip tape, reducing EC_e in the WELL treatment beds from 4.68 to 2.77 dS/m (Table 2). Comparing these numbers with the increased soil salinity in the new pistachio rows shows the impact of salt accumulation from horizontal "subbing" of water and salts moving away from the drip hose. Pistachios trees and soil samples were centered between two drip hoses (0.46 m either side of the tree) following the 2004 cotton, while cotton and its respective soil samples are directly above and vertically in line with the drip tape. Even though subbing is good in this fine sandy clay loam, leaching directly under the drip tape is significantly greater compared to the soil between beds only 0.5 m away. As effective winter rainfall was minimal (< 75 mm), lateral and upward subbing of salts in the water from the driptape into the cotton beds also created nearly identical salinity levels in the seeding zone of both the AQUEDUCT and WELL treatments, averaging > 4 dS/m and concentrating salts to the south side of the bed (Fig. 1).

For cotton, Table 2 shows that 2005 applied water and average soil matric potential was significantly less than in 2004, indicating fairly efficient irrigation. However, total salt and Cl balances indicate that anywhere from 20 to 30% leaching occurred, even in the AQUEDUCT treatment, directly below the drip tape. The reason for this contradiction is unclear.

Plant Data, Specific Ion Toxicity, Yield, EC_a and NDVI

Table 3 shows that Cl concentration in cotton petioles in the BLEND and WELL treatments increased significantly over the fresh water AQUEDUCT treatment in both 2004 and 2005. Boron concentration in cotton petioles increased significantly by 19% in the WELL treatment only in 2005, while leaf B concentrations in both cotton (data not shown) and pistachio (Table 3) about doubled for the BLEND and tripled for the WELL treatments compared to the AQUEDUCT treatment. However, even at 447 mg/kg in cotton leaves and 673 mg/kg B in pistachio rootstock leaves there were no visual symptoms of plant toxicity. The maximum saturation extract B in all soil tests was 3.6 mg/kg, despite the addition of as much as 65 kg/ha/year in the WELL treatment. A nitric acid extraction revealed that total B in the native soil was 22 mg/kg dry soil, indicating the significant adsorption potential of this soil that, for the time being helps mitigate toxicity impacts. Eventual saturation of adsorption sites is a potential problem later on.

Cotton plant height and increase in pistachio trunk circumference were unaffected by salinity. Cotton lint yield was also not significantly impacted by salinity, actually averaging higher for the WELL treatment in 2004 and the BLEND in 2005 (Table 3).

The depth-specific average EC_a ranged from 1.44 to 2.67 dS/m for field 9-1 and from 2.00 to 2.64 dS/m for 9-3. The maximum EC_a readings over the four sampling depths for both fields ranged from 3.5 to 7.2 dS/m. NDVI values for cotton in 2004, which have a possible range of -1 to +1, were not affected by salinity, being 0.751 for the AQUEDUCT, 0.734 for the BLEND and 0.716 for the WELL treatment. Correlation analysis of plot values of NDVI with the EMv (EC_a) values generated with the EM38 probe for the same plots yielded a weak R^2 of only 0.414 and 0.352 for correlation of NDVI and lint yield.

CONCLUSION

Large-scale commercial production of cotton and development of pistachios was unaffected by salinity for the first two years of this trial at an irrigation water EC of 5.4 dS/m and B concentration of 11 mg/L. In general, the end of season soil salinity doubled under saline irrigation compared to fresh water, but was sufficiently reduced by 200 mm of winter leaching with fresh water to prevent adverse impacts the second year. However, salts continued to accumulate in the cotton seedbed, even in the fresh water treatment. This is a common problem for all buried drip installations where winter rainfall is insufficient for leaching salts below the depth of the tape. Despite the application of 450 mm of fresh water for winter leaching and germination irrigations, the size and vigor of cotton plants in the WELL treatment was significantly reduced in the third year compared to the AQUEDUCT treatment. Replicated analyses from dedicated monitoring sites to a depth of 0.15m showed no treatment difference in seedbed salinity (EC = 10-12 dS/m) but spot sampling in problem areas indicated a 30% higher EC for the WELL treatment. As of June 2006, general growth of pistachio trees and the development of the young Kerman scaffolds were unaffected by saline irrigation treatments, indicating that long-term management of pistachio trees using saline water and drip irrigation may be easier than cultivation of cotton and management of seedbed salinity.

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Literature Cited

Ayars, J.E., Hutmacher, R.B., Schoneman, R.A., Vail, S.S. and Pflaum, T. 1993. Long term use of saline water for irrigation. Irrigation Science 14(1):27-34.

Ayers, R.S. and Westcott, D.W. 1985. Water quality for agriculture. United Nations FAO Irrig & Drainage Paper No. 29, Rev.1.

Fardooel, A.R. 2001. Evaluation of salt and drought resistance of two pistachio species (Pistacia chin-up and *P. musica*) in terms of growth and ecophysiological characteristics. Ph.D. dissertation. University of Ghent, Belgium.

Ferguson, L., Sanden, B. and Grattan, S. 2003. Salinity tolerance of pistachio rootstocks. Annual Report, UC Salinity/Drainage Program Water Resources Center and Prosser Trust, 2002-2003, p.13-27.

Ferguson, L., Poss, P.A., Grattan, S.R., Grieve, C.M., Want, D., Wilson, C., Donovan, T.J. and Chao, C.T. 2002. Pistachio rootstocks influence scion growth and ion relations under salinity and boron stress. J. Amer. Soc. Hort. Sci. 127(2):194-199.

Fulton, A.E., Oster, J.D., Hanson, B.R., Phene, C.J. and Goldhamer, D.A. 1991. Reducing drainwater: Furrow vs. subsurface drip irrigation. California Agriculture 45(2):4-7.

Oster, J.D., and Rhoades, J.D. 1990. Steady-state rootzone salt balance. p.469-481. In: K.K. Tanji (ed.), Agricultural Salinity Assessment and Management, ASCE Manuals and Reports on Engineering Practice No. 71. ASCE, New York.

Pruitt, W.O., Fereres, E., Kaita, K. and Snyder, R.L. 1987. Reference Evapotranspiration (ETo) for California. UC Bulletin 1922.

Sanden, B.L., Ferguson, L., Reyes, H.C. and Grattan, S.C. 2004. Effect of salinity on evapotranspiration and yield of San Joaquin Valley pistachios. Acta Hort. 664:583-589.

Shennan, C., Grattan, S.R., May, D.M., Hillhouse C.J., Schactman, D.P., Wander, M., Roberts, B., Tafoya, S., Burau, R.G. and Zelinski, L. 1995. Feasibility of cyclic reuse of saline drainage in a tomato-cotton rotation. J. Environ. Qual. 24 (3):476-486.

Wu, L. 2004. Windows-based water suitability determination model (WATSUIT). Univ. CA, Riverside. http://envisci.ucr.edu/index.php?file=faculty/wu/wu.html.

Tables

Table 1. Average water quality for all irrigation treatments.

Irrigation treatment	pH	EC (dS/m)	SAR	Ca (meq/L)	Mg (meq/L)	Na (meq/L)	Cl (meq/L)	B (mg/L)	HCO_3 (meq/L)	CO_3 (meq/L)	SO_4 (meq/L)
Aqueduct	7.4	0.50	2.5	1.2	0.9	2.6	2.0	0.3	1.6	<0.1	0.9
Blend	7.4	3.01	4.0	12.2	7.3	12.1	16.9	6.0	1.5	<0.1	12.4
Well	7.4	5.36	5.5	23.4	14.0	23.0	33.5	11.1	1.5	<0.1	24.0

Table 2. Seasonal applied water, available soil water, matric potential, total salt and chloride balance for 2004 and 2005.

Treat-ment	Fresh Water to Establish (mm)	In-season Applied (mm)	[1]Mean Available Water Content (%)	[2]Mean Matric Potential to 1.2m (kPa)	[3]Mean Spring Soil EC to 1.5m (dS/m)	Mean Fall Soil EC to 1.5m (dS/m)	[4]Total Increase in Soluble Salts (kg/ha)	Total Salts Applied in Irrigation (kg/ha)	Measured Salt Increase / Applied (%)	Measured Chloride Increase / Applied (%)
2004 COTTON					**3/22/04**	**10/6/04**				
Aque	193	628	68%a	-37a	2.07	2.71a	3787	2007	189%	304%
Blend	213	627	70%a	-33a	2.53	4.08b	9044	12075	75%	96%
Well	155	686	95%b	-22b	2.10	4.68b	15054	23522	64%	74%
2005 COTTON					**4/20/05**	**10/18/05**				
Aque	235	572	67%a	-72a	1.75	1.42a	-1925	1830	-105%	71%
Blend	196	558	77%b	-48b	2.72	3.71ab	5776	10736	54%	77%
Well	228	533	71%ab	-40b	2.77	4.74b	11494	18281	63%	83%
2005 PISTACHIO (2.8m subbing zone)					**4/10/05**	**10/18/05**				
Aque	176	434	87%	-46a	3.22	2.87a	-2042	1388	-147%	-21%
Blend	132	477	92%	-35b	4.65	4.12ab	-3092	9176	-34%	-15%
Well	231	462	92%	-38b	4.52	4.44b	-467	15818	-3%	6%

Means separation Fischer's Protected LSD. Small letters $P<0.05$.

[1]To 1.8m as determined by neutron backscatter. Refill water content of 9.1% and a field capacity of 25.8%

[2]As determined by Watermark electrical resistance blocks at 0.3, 0.6 and 1.2m depths.

[3]Weighted average of the saturation extract EC of 4 soil samples taken from 0-0.15, -0.45, -0.9 and 0.9-1.5m depths.

[4]Increased mass of salt = increase in EC*(640ppm/dS/m) * 1.5m * 15 million kg/ha-m * 0.407, the average SP%.

Table 3. Petiole/leaf N-P-K and specific ion concentrations, plant characteristics and cotton lint yield for 2004 and 2005.

Treat-ment	NO3-N (ppm)	NH4-N (ppm)	PO4-P (ppm)	K (%)	Na (ppm)	Cl (%)	B (ppm)	[1]Cotton Ht, ΔPistachio Circum (mm)	Cotton Lint Yield (kg/ha)
Petioles 8/27/04					**Cotton 2004**			**9/14/04**	**10/6/04**
Aque	170	75	368	1.84	570	2.58a	34	1072b	2166
Blend	273	95	463	1.73	712	3.23B	37	909a	2161
Well	548	108	413	1.72	574	3.00b	37	986b	2259
Petioles 9/15/05					**Cotton 2005**			**9/15/05**	**10/19/05**
Aque	403	53	760	2.06	605	2.71a	42a	1055	1070
Blend	158	40	573	1.79	539	3.13b	46a	1093	1266
Well	288	85	593	1.91	546	3.38B	50B	1069	1120
Rootstock Leaves 9/15/05					**Pistachio 2005**			**10/19/05**	
Aque	63	160	580	1.02	222	0.27a	194a	27	
Blend	55	128	545	1.06	220	0.27a	492B	24	
Well	65	148	500	1.08	314	0.38B	673B	24	

Means separation Fischer's Protected LSD. Small letters $P<0.05$, capital letters $P<0.01$.

[1]Cotton height 9/15 and increased pistachio trunk circumference from 6/2 - 10/19/05.

Figures

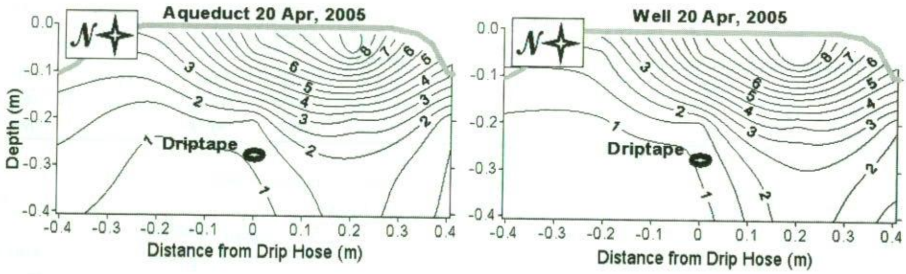

Fig. 1. Contours of cotton bed salinity (EC_e) at emergence for Aqueduct and Well treatments following application of 230 mm of fresh water (0.5 dS/m) during the winter and spring.